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Fatigue Behavior of Repaired Cracks with Composite Patches Bonded with Adhesive: A Review

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Abstract

Repair of cracks in materials by the composite patch is one of the best methods. A composite patch is a repair procedure that keeps the weight of the original material almost unchanged. Researchers who worked in the repair of materials for decades contributed to the restoration of cracks, notches, and fractures, leading to improvement in service life and corrosion resistivity. Also, simple conformance to sophisticated aerodynamic shapes corresponds to the retardation of the Stress Intensity Factor (SIF). This paper focuses on the advantages of the patch and various research on fatigue crack growth is presented.

Keywords

Repair technique, Composite patch, Crack growth, Fatigue life

Introduction

Defects like abrasion, crack, and notch can compromise structural integrity and reduce material life. There are various methods of repair like vee-and-weld, metal crack stitching, stop-hole technique, laser additive crack cladding, and bonded crack patches. One of the best methods of repair [1] without introducing any new filler material or introducing additional holes is adhesive bonded composite patches, and the structure doesn't get weaker. Cracks can expand and lead to complete component fracture, imposing massive dangers to component life and perhaps resulting in fatalities or serious injuries. Therefore, repairing is essential. The discovery of any fissures prompts quick action to stop the cracks from propagating to the point of breakage.

The main advantages of a patch repair are uniformly distributed stress transfer through bonded enhanced fatigue life, reduced SIF, and structural integrity. Patches are good with strength-to-weight ratio and aerodynamic contour, easy to handle. Installing patch requires less skill when compared to welding. If we consider a case like repairing a gas pipeline where it is impossible to weld due to flammable conditions, the path plays a huge role in repair technique. Astronauts also carry patches with them in case of an emergency, the repair can be done without any hassle.

Research also indicated that adhesives are one of the best methods to repair a crack, injecting epoxy resin [2] or applying a composite material patch with the epoxy adhesive. There is a significant growth in the fatigue life of the parental material with a proportional decrement in SIF and SCF (Stress Concentration Factor). Bonded patch repairs can prevent, or delay crack re-initiation or propagation. The Finite Element Method plays a vital role in optimizing patch shapes, reducing the SCF, J-integral, and SIF and increasing the fatigue life of the parental material.

Applications

The patch repair technique is used in many industries like construction, ship manufacturing, aerospace, and oil and gas. The patch fails mainly due to an increase in SCF, SIF, peel stress, moisture absorption, and delamination [3-5]. Most functional aeronautical components are subjected to variable amplitude cyclic load. This load directly impacts the crack propagation rate [6]. To be precise, patches are used in statically loaded components like blades of helicopters, not on dynamic parts like a rotary shaft of a turbine or helicopter, until and unless it is an emergency [7-9]. Fissures generated due to lack of function while welding may propagate in the cylindrical pipeline and pressure vessels and cause severe damage to the system [10]. Repairing of pipelines using glass epoxy composite patches was done which can withstand the pressure of the fluid while working to avoid failure [11].

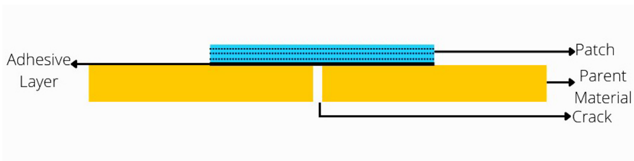

Figure 1: Parts of repair technique.

Fatigue Crack Growth

In this section, the fatigue life and crack growth rate of the repaired metals are scrutinized. The fatigue life of fractured aluminum structures repaired with composite patches is significantly increased. The repaired adhesive layer also affects the life of the repaired structure. Failure of the adhesive layer significantly reduces the fatigue life of restored structures. Materials like boron/epoxy [12], graphite/epoxy [13], carbon/epoxy and glass/epoxy [14] are used in the case of patching. The reduction of stress concentration in epoxy/boron patch is more in comparison to graphite/epoxy patch. A Notch creates more impact on SIF and SCF than a crack; Figure 3 shows the reduction of SIF up to 52% - 46% for the boron and graphite epoxy, respectively [15]. As SIF decreases, the fatigue life increases drastically. For the Al-6061, graphite patches extended the specimen's fatigue life by 28% greater than boron-epoxy

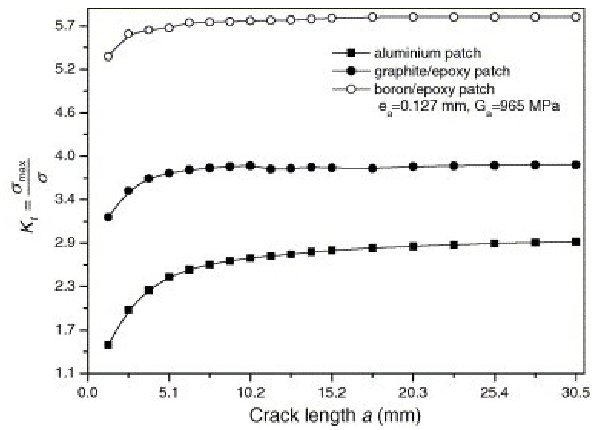

Figure 3: SCF as a function of crack length [15].

patches [12]. Fatigue life increased by 2000% and 4800% for double-sided patches compared to unpatched samples at stress ratios of 0 and 0.5, respectively [14]. Many studies have shown the fatigue behavior of repaired AL-7075-T6 [13, 14]. The order in which the overload is applied has a significant impact on repair performance. When the overload is applied after bonding the patch, it not only retards fracture growth but also destroys the patch repair. According to the fractographic investigation [16], using overload before patch bonding resulted in high failure circumstances and infinite fatigue life for the repaired plate.

Figure 4 shows the comparison of fatigue crack growth for patch and unpatched material [17]. The 'a' vs 'N' curve describes the behavior of patched specimens under fatigue loading for various initial crack lengths. Early detection of cracks and patching increases fatigue life magnificently. As the crack length grows, the stress intensity factor displays asymptotic behavior shown in figure 3. Also, repair effectiveness does not improve for increasing amplitude loading. However, it does improve slightly for lowering amplitude loading.

In the research work done on the Mode of loading [18], the presence of the patch has a greater impact on the Mode I stress intensity factor than on the Mode II stress intensity factor in the mixed mode. The researcher [14, 16] conducted experimental and computational studies on CFRP sheets.

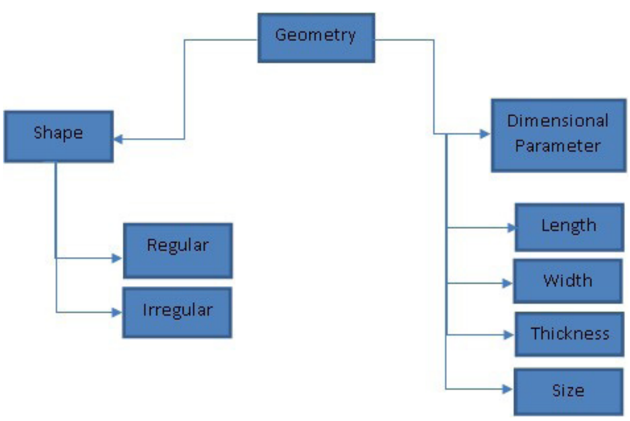

Figure 2: Parameters of patch that affects repair effectiveness.

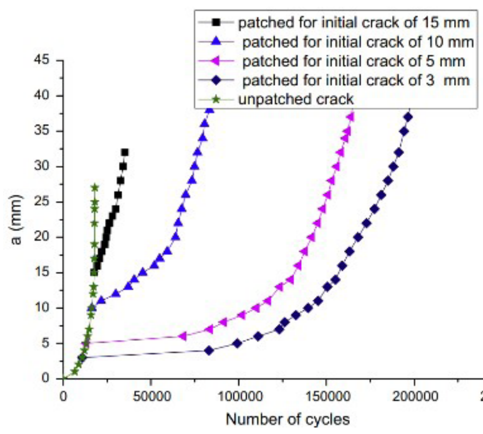

Figure 4: Fatigue life of patched and unpatched specimen [17].

Table 1: Findings of various papers.

Sl. No	Base Material	Patch Material	Important conclusions		Parameter	Reference
1	Al 2024-T3	Boron/ Epoxy	Debonding was found to be dependent on length of the crack. Fatigue life increases from 4.3 to 7 times.		Crack length	[27]
2		Glass, Boron and Graphite/ Epoxy	Various patch material was tested, and graphite stood out to be most optimistic.		Better patch material	[28]
3		Carbon/ Epoxy	The patch decreases the SCF.		Notch shape effects the life of parent material	[13]
			Patched specimen (Percentage increment in fatigue life)	**Notch shape**		
			71.4%	Circular		
			78.2% and 70%	Elliptical a/b = 4 and a/b = 2		
			70.5%	V Shape		
4	Al 1050	Glass/ Epoxy	Min fatigue life in stress ratio 0 is (2000%) [Single sided patch]. Max Fatigue life in stress ratio 0.5 is (4800%) [Double sided patch]. Fatigue life in stress ratio 0.75 is (1800%) [Single sided patch]		Comparison of single- and double-sided patch	[14]
5	Al 7075-T6	Carbon/Epoxy	Aging of patch effects, the performance of patch by 14%.		Aging of patch	[29]
6	Al 2024-T3 and Al 7075-T6	Glass/ Epoxy	Al7075-T6 showed better performance.		Better parent material	[30]

Compared to the unpatched sample, the repair technique increased fatigue life by 2.2 - 7.9 times for double-sided repairs. To forecast fracture propagation and fatigue life of steel plates, a theoretical model was suggested. CFRP with superior modulus was used in the repair, and it was proven that adopting CFRP materials with greater modulus improved the effectiveness of the strengthening [19-21].

In Figure 5, there is a comparison of the fatigue life of the unpatched, single patch and the double patch of boron/epoxy. The life of the patch specimen was 3.88 times greater than the unpatched one [22]. The overall fatigue life of the patched specimen was 22.18 times that of the unpatched, demonstrating that the suggested approach was capable of significantly enhancing the fatigue parameters of fractured aluminum-alloy pipe [23]. Researchers [24] conducted tensile and fatigue tests on notched aluminum material repaired with boron fiber patches manufactured using pre-impregnating process, and found that the life was improved by 5 to 14 times that of the unpatched specimen. The influence of a single patch on the SIF and fatigue life of a centrally cracked thick aluminum plate was investigated [25]. A fatigue test on CFRP revealed that the reinforced member's stiffness was significantly reduced due to the infinitely slow debonding of the adhesive, which is often the weakest link in FRP [26].

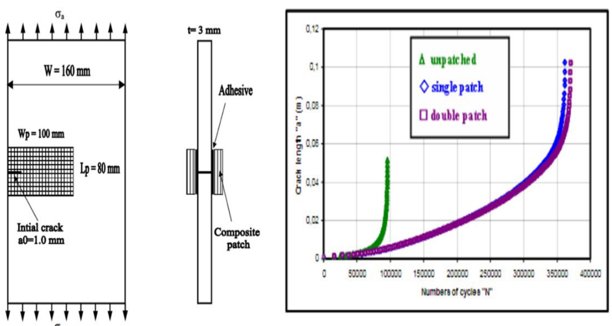

Figure 5: Comparison of patched and unpatched specimens [22].

Conclusions

Although composite patch repair technology is widely used worldwide, it is also critical to create more efficient repair technologies compared to routinely used composite patch repair. This paper focuses on the fatigue crack growth behavior of various patches. The following conclusions were drawn from various studies (Table 1):

- A patch always increases fatigue life irrespective of the parent material.
- A patch can decrease the stress concentration and intensity of the crack up to 90%.
- Debonding always leads to failure in most fiber-reinforced cases.
- The bonded patch repair can prevent or retard the crack re-initiation and crack propagation.
- In the case of fatigue loading, the unpatched specimen always fails first in comparison to a single or double patch.
- As the crack length grows, the stress intensity factor displays asymptotic behavior.

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None.

Conflict of Interest

The authors declare no conflict of interests.

Credit Author Statement

Subhajith Roy: Data curation, Writing - original draft preparation; Dharmendra Kumar Shukla: Writing - review and editing. All the authors read and approved the manuscript.

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